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SLIDING FRICTION OF SOME MEMBERS OF THE PLATINUM METALS GROUP

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SUMMARY

An investigation was conducted to determine the friction properties of some members of the platinum metals group. The metals examined in this investigation were ruthenium, rhodium, osmium, and iridium. Rhodium, ruthenium, and iridium were observed in sliding contact with themselves, while osmium was in sliding contact with iridium. The hexagonal metal ruthenium and the face-centered cubic metal rhodium were also made to slide in contact with polycrystalline aluminum oxide. The friction experiments were conducted at ambient pressures from 760 to 10^{-11} torr (1.0×10^5 to 1.33×10^{-9} N/m²) with a hemispherically tipped rider sliding on a rotating flat disk. Experiments were conducted at sliding velocities of 0.001 and 200 centimeters per second, at ambient temperatures from 20° to 500° C, and at loads from 50 to 1000 grams. Specimens were outgassed and cleaned by electron bombardment for 30 minutes at 400° C prior to each experiment.

The results of this investigation show that the face-centered cubic platinum metals rhodium and iridium exhibit markedly higher friction coefficients at low ambient pressures (10^{-11} torr or 1.33×10^{-9} N/m²) than the close-packed hexagonal metals osmium and ruthenium. Stick-slip motion was observed with the face-centered cubic metal rhodium, but not with the hexagonal metal ruthenium under identical conditions.

While surface contaminants influence both the face-centered cubic and hexagonal platinum metals, surface contaminants had the greatest effect on the face-centered cubic metal rhodium. Friction data for the hexagonal metals osmium and ruthenium correlate with the fundamental relation between the friction coefficients of hexagonal metals and their c/a lattice ratios established in an earlier study. Friction decreased with increasing lattice-parameter ratio c/a .

INTRODUCTION

The platinum metals, Group VIII on the periodic table, have some interesting properties useful in the field of lubrication. The metals of this group are ruthenium, rhodium,

palladium, osmium, iridium, and platinum. The high values of elastic modulus and hardness, and the high melting points, as well as the good corrosion and wear resistance of some of these metals have made them useful in applications such as sliding electric contacts, switches, slip rings, and coatings.

The differences in the physical and mechanical properties of these metals are reflected in the differences in their friction properties. For example, osmium has three times the modulus of elasticity of platinum (ref. 1) and approximately nine times the hardness (ref. 2). Elasticity and hardness have been shown to be related to adhesion (ref. 3) and, therefore, can be expected to influence friction. The greater the elastic modulus and the hardness, the lower the observed adhesion (ref. 3). Further, platinum is a face-centered cubic metal, while osmium is a close-packed hexagonal metal; and crystal structure has been shown to influence adhesion (ref. 3) and friction (ref. 4). The face-centered cubic metals, in general, exhibit higher adhesion and friction coefficients than close-packed hexagonal metals.

The friction and wear properties of platinum and palladium have been measured in air (ref. 6), and the friction of platinum has been measured in vacuum (10^{-6} torr or 1.33×10^{-4} N/m²) (ref. 7). Based on physical and mechanical properties, platinum and palladium should have the highest friction of the platinum metals, while osmium might be expected to have the lowest friction properties.

This investigation was conducted to examine the friction properties of some of the Group VIII elements. The metals studied were ruthenium, rhodium, osmium, and iridium. Friction experiments were conducted primarily in vacuum (10^{-11} torr or 1.33×10^{-9} N/m²) after surfaces were cleaned by electron bombardment. Some experiments were conducted at various ambient pressures to determine the influence of atmospheric contaminants (oxides, adsorbed gases, etc.) on the surface. Because of the similarity in physical properties of rhodium and ruthenium and their difference in crystal structure (and the properties related to it), these two elements were compared as to their friction behavior. A similar comparison was made for iridium and osmium. Experiments were conducted with a hemispherical rider in contact with a rotating flat disk at loads from 50 to 1500 grams, sliding velocities of 0.001 and 200 centimeters per second, and temperatures from 20° to 500° C.

APPARATUS

The apparatus used in this investigation is shown in figure 1. The basic elements of the apparatus were the specimens (a $2\frac{1}{2}$ -in. -diam (6.35 cm diam) flat disk and a $\frac{3}{16}$ -in. -rad. (0.48 cm rad.) rider) mounted in a vacuum chamber. The disk specimen was driven through a magnetic drive coupling. The coupling consists of two 20-pole magnets 0.150 inch (0.38 cm) apart with a 0.030-inch (0.076 cm) diaphragm between the magnet faces.

The driver magnet that was outside the vacuum system was coupled to a hydraulic motor or to a small instrument motor for slow-speed experiments. The driver magnet was completely covered with a nickel-alloy housing and was mounted on one end of the shaft within the chamber (fig. 1). The end of the shaft that was opposite the magnet held the disk specimen.

The rider specimen was supported in the specimen chamber by an arm that was mounted by gimbals and bellows to the chamber. A linkage at the end of the retaining arm away from the rider specimen was connected to a strain-gage assembly. This assembly was used to measure frictional force. Load was applied through a dead-weight loading system.

Attached to the lower end of the specimen chamber was a 500-liter-per-second ionization pump and a sorption pump. The pressure in the chamber was measured adjacent to the specimen with a cold-cathode ionization gage. In the same plane as the specimens and ionization gage was a diatron-type mass spectrometer (not shown in fig. 1) for determination of gases present in the vacuum system. A 20-foot-long (6.1 m long) stainless-steel coil of 5/16-inch-diameter (0.79 cm diam) tubing was used for liquid-nitrogen and liquid-helium cryopumping of the vacuum system.

In experiments where external heating of the specimens was required, an electron gun was used (fig. 1). A thermocouple was inserted in the rider, and the bulk specimen temperature was recorded. No attempt was made to record interface temperatures.

SPECIMEN FINISH AND CLEANING PROCEDURE

The disk and rider specimens used in the friction and wear experiments were finished to a roughness of 4 to 8 microinches (1 to 2×10^{-4} mm) and were then fully annealed. Before each experiment, the disk and the rider were given the same preparatory treatment: (1) thorough rinsing with acetone to remove oil and grease, (2) polishing with moist levi-gated alumina on a soft polishing cloth, and (3) thorough rinsing with tap water followed by distilled water. For each experiment, a new set of specimens was used.

RESULTS AND DISCUSSION

The properties of the platinum metals, rhodium, ruthenium, iridium, and osmium, are presented in table I. Despite the similarity in many properties of rhodium and ruthenium, such as melting and boiling points and density, there is a difference in the crystal structure of these metals; rhodium (atomic number 45) has a face-centered cubic structure, while ruthenium (atomic number 44) has a close-packed hexagonal structure. Iridium and osmium also have similar melting and boiling points as well as similar den-

sities but are different in crystal structure. Iridium (atomic number 77) has a face-centered cubic structure, while osmium (atomic number 76) has a close-packed hexagonal structure. Differences in hardness in the pairs of Group VIII elements studied are reflected in the differences in their crystal structure. For example, annealed rhodium has a Vickers hardness number (VHN) of 110 while ruthenium has over twice that hardness, a VHN of 240. Similarly, iridium has a VHN of 220 while osmium has a VHN of 350 (table I).

In addition to the metals examined herein, the platinum metals family contains the elements palladium and platinum. The friction properties of palladium are examined in reference 6 and those of platinum in reference 7.

In reference 7, the only property of the metal platinum which is examined in detail is the influence of outgassing temperature on the friction characteristics of polycrystalline platinum in sliding contact with itself. The platinum was outgassed at various temperatures in these experiments, and the specimens were then cooled to room temperature prior to the friction experiment. The results obtained in some of the experiments described in reference 7 are presented in figure 2. The results indicate that friction is dependent on the presence of dissolved gases in the metallic platinum and that, as the outgassing temperature is increased and the concentration of dissolved gases reduced, the friction coefficient of platinum increases rather markedly.

The influence of dissolved gases on the friction coefficient of a metal is, however, affected by and dependent on the past metallurgical history of that metal. For example, had the platinum of figure 2 been refined in a vacuum environment, it is certain that the resulting curve would have an entirely different shape than that shown in figure 2. Thus, where the presence of gases is minimum in vacuum-zone-refined metals, the outgassing temperature should not be as critical as in those experiments where ordinary metals are used without any prior outgassing. The platinum metals examined in this investigation were all vacuum-zone-refined (triple pass) metals with a minimum amount of gaseous inclusions. Therefore, the effect of outgassing on the friction properties of these metals would not be great. In all the vacuum experiments conducted at 10^{-11} torr (1.33×10^{-9} N/m²), however, the specimens were electron bombarded at 400° C for 30 minutes prior to the experiment to ensure freedom from surface contamination.

Friction experiments were conducted with metallic rhodium and ruthenium at various loads and temperatures in a vacuum environment. The results obtained in these experiments are presented in figure 3. Changing load has some influence on the friction properties of rhodium in sliding contact with itself (fig. 3(a)). At loads to 500 grams, the friction coefficient decreased with increasing load. Above 500 grams, however, changes in load had little influence on friction. As load was increased, the friction coefficient of rhodium decreased to 1.5 at 500 grams and remained at an average value of 1.5 at loads to 1000 grams. Since the friction coefficients were very erratic, they

were plotted as a band showing the minimum and the maximum and an average value. Unlike rhodium, however, ruthenium in sliding contact with itself exhibited little change in friction coefficient with increase in load over the range from 100 to 1000 grams (fig. 3(a)). At loads from 500 to 1000 grams, the friction coefficient of rhodium was twice that for ruthenium. At all loads and temperatures studied ruthenium exhibited the lowest and least erratic friction coefficient.

Rhodium in sliding contact with itself exhibited the classical stick-slip type of sliding motion, as shown in figure 3(c). Friction coefficients varied from 1.0 to 2.0. At the end of the slip portion of the trace, friction coefficients of 1.0 were obtained. At the end of the stick portion, friction coefficients of 2.0 were obtained. In contrast to the face-centered cubic metal rhodium, ruthenium in sliding contact with itself had no tendency for marked stick-slip motion (fig. 3(c)). There is a marked difference in the friction traces obtained for rhodium and ruthenium in sliding contact with themselves.

Experiments were conducted in a vacuum environment with the same two metals in sliding contact with themselves to examine the influence of temperature on friction properties. The friction coefficients of these metals obtained at various temperatures are shown in figure 3(b). Rhodium at a load of 100 grams gave friction coefficients of 2.5 to 5.0 at room temperature. With increases in temperature to 100° and 200° C, the average friction coefficient increased from 3.75 to 4.00. For the hexagonal metal ruthenium in sliding contact with itself, however, the friction coefficient remained relatively unchanged at 0.70 at ambient temperatures from 20° to 500° C. The cubic metal rhodium has a friction coefficient four times as great as that of the hexagonal metal ruthenium. This difference in friction and the similarity in various other properties of the two metals markedly point to the influence of crystal structure on the friction behavior of metals.

The results of figure 3 are particularly interesting in light of the fact that rhodium is most frequently used as a slider surface in sliding electric contacts. Usually rhodium is used in this application as a plating on the surface of copper or some other metal. From the results obtained in this investigation, it would appear that ruthenium, with its hexagonal crystal structure, would certainly be highly superior to the face-centered cubic metal rhodium in sliding-electric-contact applications. This superiority results not only from the difference in friction coefficients but also from the stick-slip behavior of rhodium. Stick-slip motion is certainly undesirable with respect to the establishment of contact area and also presents problems associated with noise.

Some of the metals least sensitive to the presence of surface contaminants are the platinum metals. For this reason, these metals are frequently used in corrosion-resistant applications as well as in areas where the presence of contaminant surface films can be especially harmful. Friction experiments were performed to determine exactly what influence the presence of surface contaminants would have on the friction

properties of some platinum metals. The experiments were conducted with rhodium and ruthenium at various ambient pressures from 760 to 10^{-11} torr (1.0×10^5 to 1.33×10^{-9} N/m²). The results obtained in these experiments are presented in figure 4.

The data of figure 5 indicate that the presence of surface contaminants influences the friction properties of both rhodium and ruthenium. Rhodium and ruthenium at 760 torr (1011 N/m²) exhibit friction coefficients between 0.3 and 0.4, and this friction coefficient is not altered much by the reduction in ambient pressure to 10^{-8} torr (1.33×10^{-6} N/m²). At lower pressures, however, with specimen cleaning by electron bombardment, there is a marked increase in the friction coefficient of the cubic metal rhodium. The friction coefficient increases from approximately 0.3 to the range of 2.4 to 5.0.

In contrast to the marked increase in friction for the face-centered cubic metal rhodium at low ambient pressures (10^{-10} to 10^{-11} torr or 1.33×10^{-8} to 1.33×10^{-9} N/m²), stringent surface cleaning by electron bombardment of the close-packed hexagonal metal ruthenium did not result in a marked increase in friction coefficient. The friction coefficient for ruthenium increased from approximately 0.45 at 10^{-8} torr (1.33×10^{-6} N/m²) to approximately 0.55 at 10^{-11} torr (1.33×10^{-9} N/m²) after thorough electron bombardment.

Rhodium, with surface contamination, exhibited somewhat lower friction coefficients than the hexagonal metal ruthenium. Once the specimens were thoroughly cleaned in a vacuum environment by electron bombardment, however, the hexagonal metal exhibited markedly lower friction properties than the face-centered cubic metal rhodium.

In many mechanical applications, metals are not normally in sliding contact with themselves but rather in contact with other metals or with nonmetallic materials. Therefore, some friction experiments were conducted in vacuum with rhodium and ruthenium in sliding contact with the ceramic material aluminum oxide, in its polycrystalline form. Aluminum oxide was used as the mating surface primarily because an earlier investigation showed that, for metals in sliding contact with aluminum oxide, adhesion of the metal to the oxygen of the aluminum oxide results in a strong chemical bond and subsequent shear in the metal. The metal is the weaker member at the sliding interface; thus shear at the interface in the metal determines the friction force. The results obtained in two such friction experiments are shown in figure 5. The results of figure 5 for rhodium and ruthenium in sliding contact with polycrystalline aluminum oxide show that the friction coefficient for ruthenium was approximately half that obtained for the face-centered cubic metal rhodium.

The difference in friction coefficients between ruthenium and rhodium in figure 5 may then be attributed to the difference in their crystal structure (and the associated differences in their shear properties). In all the experiments conducted in this investigation at various loads and temperatures and with differing substrate materials, ruthenium consistently showed lower friction than rhodium when in sliding contact in vacuum (10^{-10} to 10^{-11} torr, or 1.33×10^{-8} to 1.33×10^{-9} N/m²).

The platinum metals osmium and iridium have extremely interesting properties which can be related to friction and adhesion. Osmium has the highest elastic modulus of any element in the periodic table. It is extremely hard and has a hexagonal crystal structure. Iridium, like osmium, has a high elastic modulus and a high hardness, but a face-centered cubic structure. Friction experiments were performed to determine the influence of crystal structure on the friction properties of osmium and iridium. The experiments were conducted in a vacuum at various loads and temperatures for iridium in sliding contact with itself and for osmium in sliding contact with iridium. It was not possible to obtain osmium disk specimens; therefore, it was necessary to slide osmium on iridium.

Friction data obtained for osmium and iridium in vacuum are presented in figure 6. Friction characteristics for both osmium and iridium were relatively unchanged with changes in load at loads to 1000 grams. The friction coefficient for osmium in sliding contact with iridium is, however, about half that for iridium in sliding contact with itself, with changing load. Again, just as with ruthenium and rhodium, crystal structure seems to influence friction markedly. The close-packed hexagonal metal osmium exhibited markedly lower friction than the face-centered cubic metal iridium. This difference in friction was observed not only at different loads in vacuum but also at various temperatures (fig. 6(b)).

The results of friction as a function of temperature shown in figure 6(b) indicate a marked difference in friction coefficients between osmium in sliding contact with iridium and iridium in sliding contact with itself. At 300° C, a nearly threefold difference in friction coefficient existed. The data of figure 6 for osmium and iridium are much like the data observed in the previous figures for rhodium and ruthenium; that is, the close-packed hexagonal metal exhibits markedly lower friction coefficients in a vacuum environment than the face-centered cubic metal.

For the hexagonal metals, a direct relation exists (ref. 5) between the friction coefficient and the ratio of interbasal planar spacing to lattice parameter a . This relation holds for some 14 hexagonal metals, as well as for hexagonal metal alloys. Friction experiments were conducted to determine if osmium and ruthenium, the two hexagonal metals of the platinum family, also correlate with the friction - lattice-parameter curve. These experiments were conducted with osmium and ruthenium in sliding contact with 440-C stainless steel under the same conditions as described in reference 5. Results obtained in these experiments are presented in figure 7, along with the results of reference 5.

Figure 7 shows that osmium falls on the friction - lattice-parameter curve established in reference 5 and that ruthenium is not far from the curve. Thus, the results of figure 7 indicate that the two hexagonal metals of the platinum family, osmium and ruthenium, correlate in their friction properties with the friction characteristics of other

hexagonal metals.

The results obtained in this investigation show that, for sliding applications of platinum metals in vacuum, it certainly would be preferable to use the close-packed hexagonal metals osmium and ruthenium. These metals exhibit markedly lower friction coefficients than the face-centered cubic metals rhodium and iridium.

CONCLUSIONS

The following conclusions are based on the results obtained in friction experiments with members of the platinum metals group, ruthenium, rhodium, osmium, and iridium:

1. The hexagonal metals osmium and ruthenium exhibit appreciably lower friction coefficients than the face-centered cubic metals rhodium and iridium in vacuum (10^{-10} to 10^{-11} torr or 1.33×10^{-8} to 1.33×10^{-9} N/m²) at various speeds and loads. These results confirm earlier data showing the superiority of hexagonal metals to face-centered cubic metals.

2. Friction data for the hexagonal metals osmium and ruthenium correlate with the fundamental relation between the friction coefficient of hexagonal metals and the lattice-parameter ratio c/a for atomic stacking.

3. Classical stick-slip motion was observed with the face-centered cubic metal rhodium; under the same conditions, the hexagonal metal ruthenium did not exhibit marked stick-slip motion.

4. Surface contaminants influence the friction coefficients of rhodium and ruthenium. The influence on rhodium is, however, considerably greater than on ruthenium.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, April 28, 1967,
129-03-13-02-22.

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TABLE I. - PROPERTIES OF SOME PLATINUM METALS

[Data from ref. 2.]

Property	Material			
	Rhodium	Ruthenium	Iridium	Osmium
Crystal structure	Face-centered cubic	Close-packed hexagonal	Face-centered cubic	Close-packed hexagonal
Lattice parameter				
a, Å	3.796	2.7003	3.8312	2.7298
c/a		1.5824		1.5790
Melting point, °C	1960	2250	2410	3000
Boiling point, °C	4500	4900	5300	5500
Thermal conductivity, cal/(°C)(cm)	0.36	0.25	0.35	0.21
Electrical resistivity at 0°C, $\mu\text{m}/\text{cm}$	4.7	7.16 to 7.6	5.3	9.5
Density at 20°C, g/cm^3	12.44	12.4	22.4	22.5
Atomic number	45	44	77	76
Vickers hardness number of annealed bar	110	240	220	350
Young modulus (annealed), kg/mm^2	2.9×10^4	4.22×10^4	5.2×10^4	5.62×10^4
Tensile strength (annealed), kg/mm^2	43	-----	22.5	-----

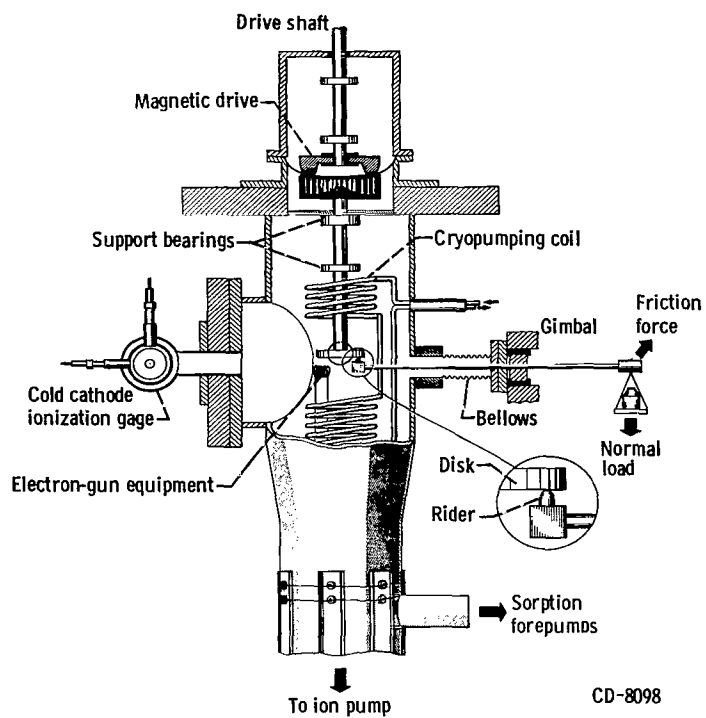


Figure 1. - Vacuum friction apparatus.

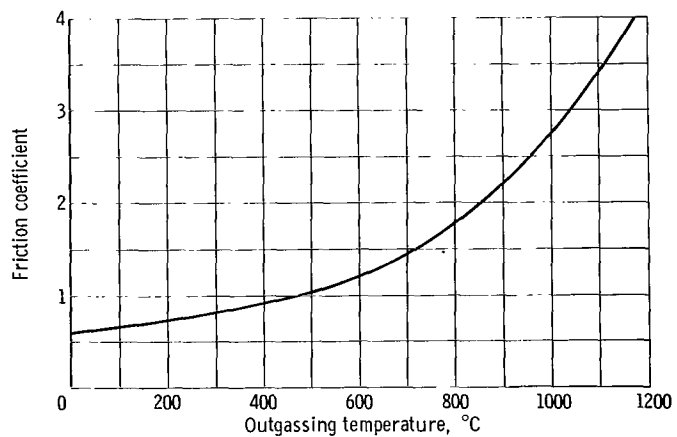
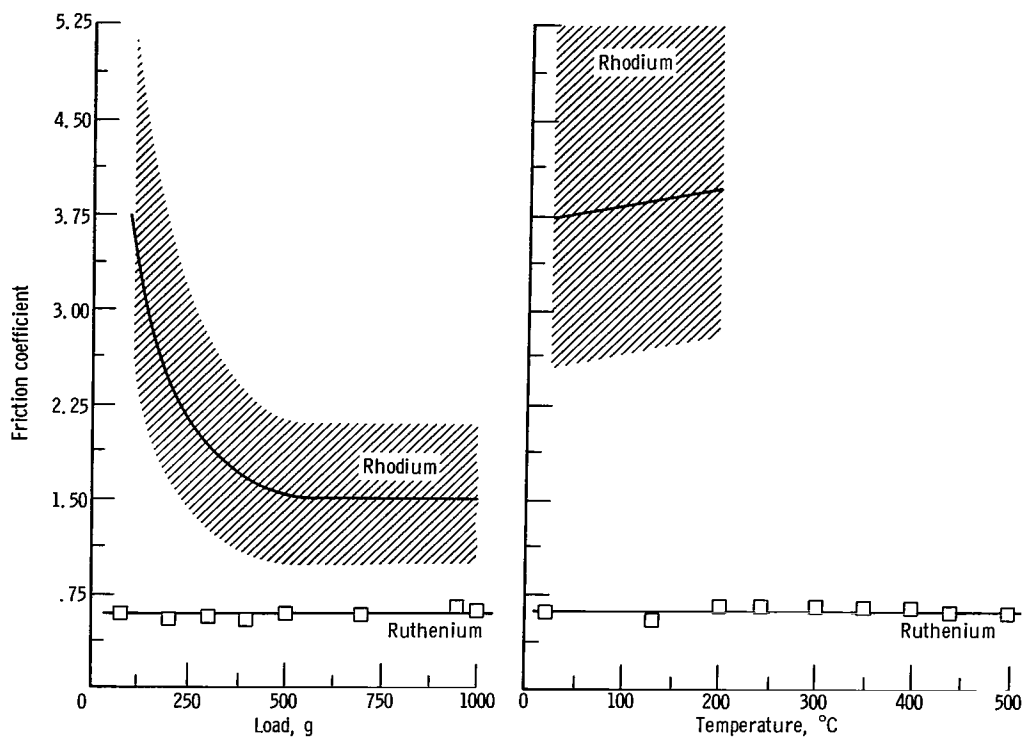
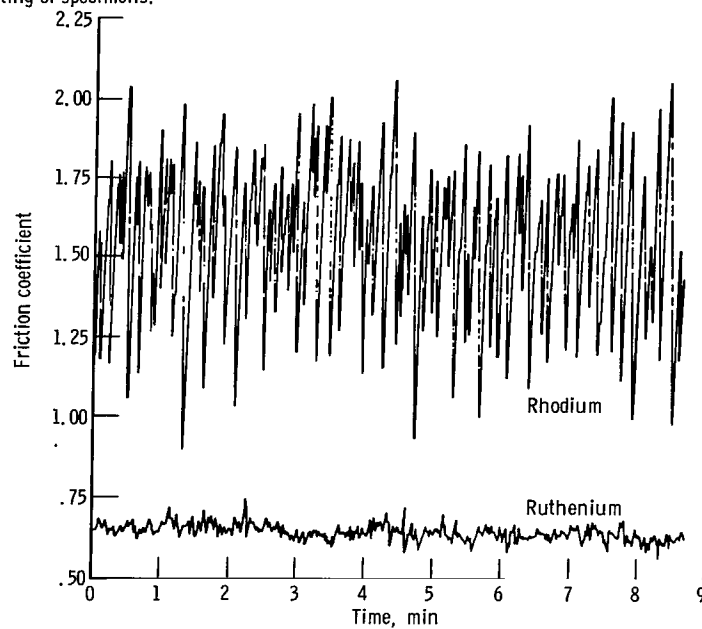


Figure 2. - Friction coefficient of platinum sliding on itself at room temperature in vacuum, as function of outgassing temperature (ref. 7).



(a) Friction as function of load; no external heating of specimens.

(b) Friction as function of temperature; load, 100 grams.



(c) Friction as function of time; load, 400 grams; no external heating of specimens.

Figure 3. - Friction coefficients of rhodium and ruthenium sliding on themselves in vacuum (10^{-11} torr or 1.33×10^{-9} N/m²); sliding velocity, 0.001 centimeter per second.

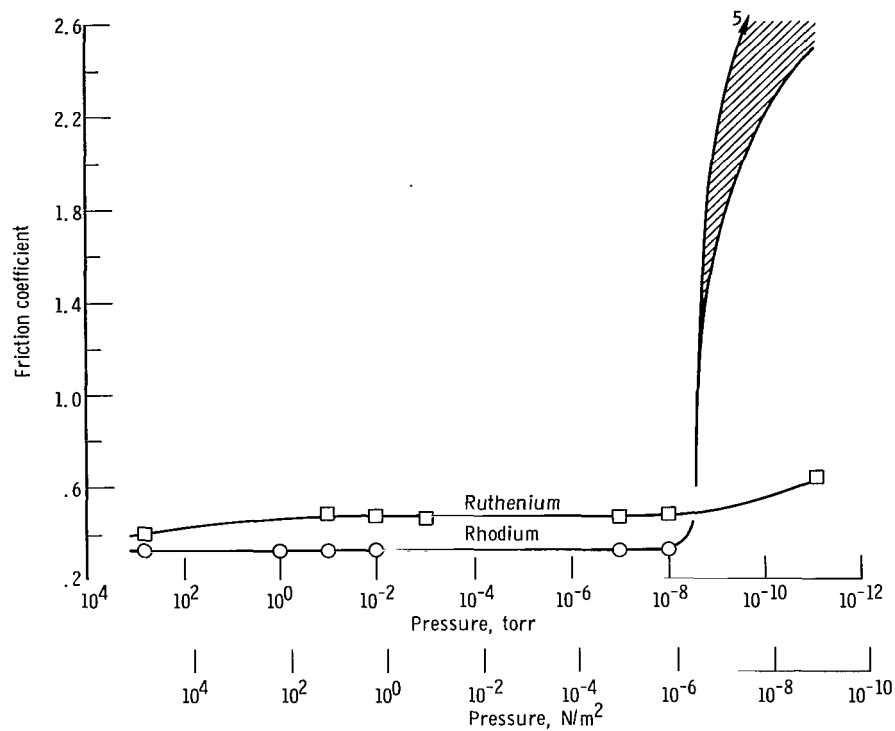


Figure 4. - Friction coefficients of rhodium and ruthenium sliding on themselves at various ambient pressures. Sliding velocity, 0.001 centimeter per second; load, 100 grams; no external specimen heating. Data obtained at 10^{-10} and 10^{-11} torr (1.33×10^{-8} and 1.33×10^{-9} N/m²) with surfaces cleaned by electron bombardment.

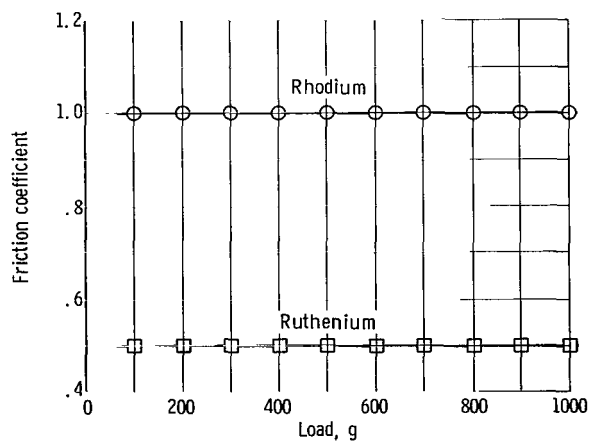
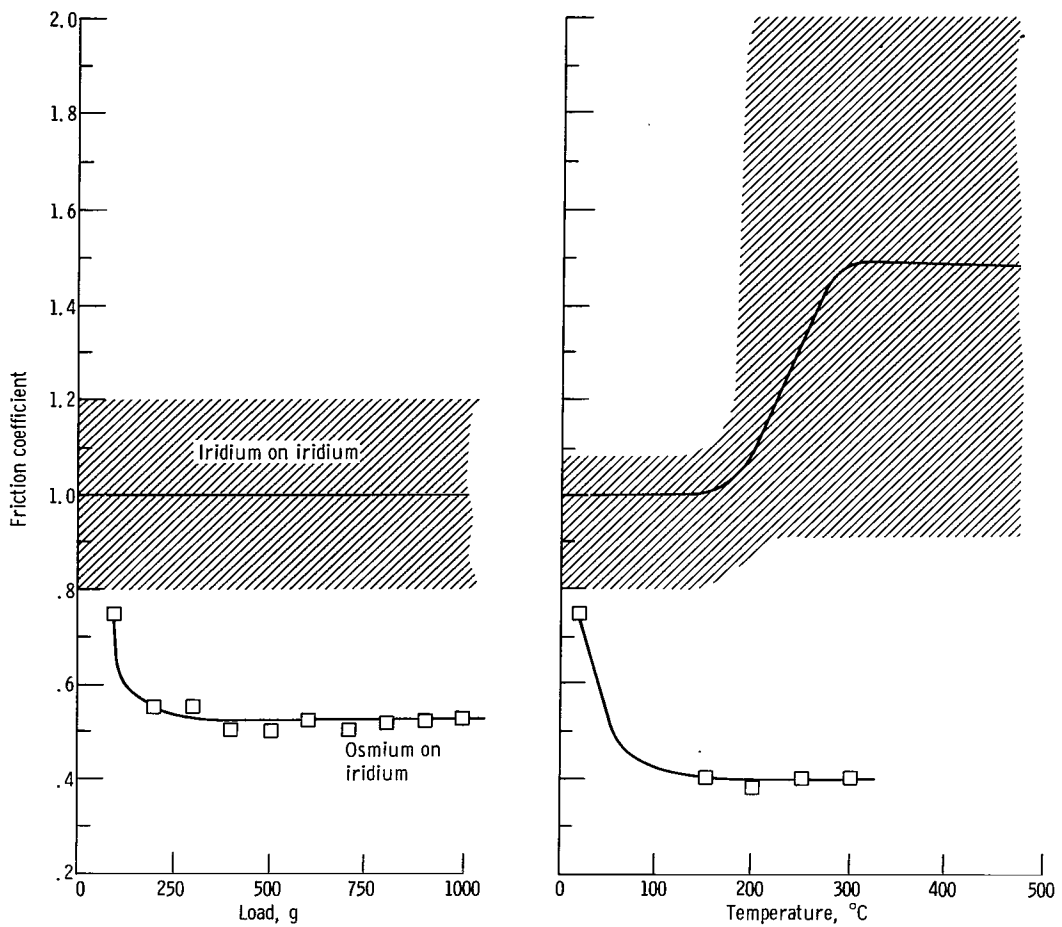


Figure 5. - Friction coefficients of rhodium and ruthenium sliding on polycrystalline aluminum oxide in vacuum (10^{-11} torr or 1.33×10^{-9} N/m²). Sliding velocity, 0.001 centimeter per second; bulk specimen temperature, 20° C.



(a) Friction as function of load; no external heating.

(b) Friction as function of temperature; load, 100 grams.

Figure 6. - Friction coefficients of iridium and osmium in sliding contact; sliding velocity, 0.001 centimeter per second.

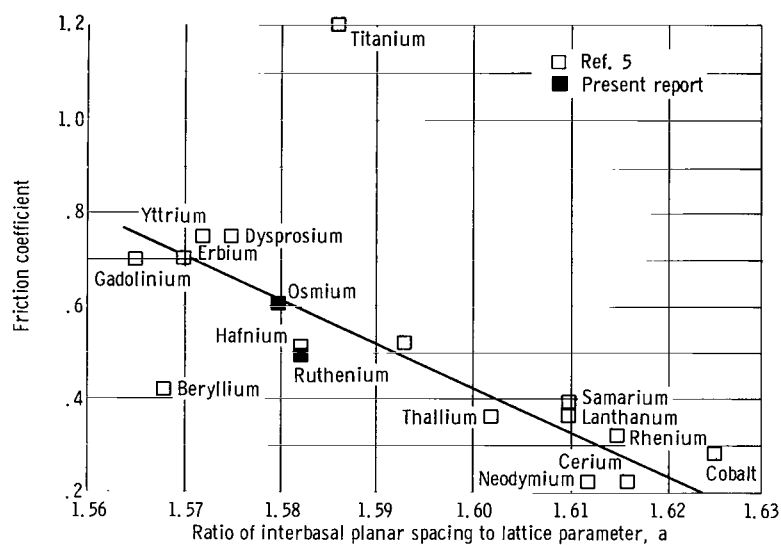


Figure 7. - Friction coefficients of various hexagonal metals sliding on 440-C stainless steel in vacuum (10^{-11} torr or 1.33×10^{-9} N/m²). Load, 1000 grams; sliding velocity, 200 centimeters per second; no external specimen heating.

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